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A CAVITY SYSTEM FOR SEAWATER DIELECTRIC MEASUREMENTS AT P-BAND

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ABSTRACT

This paper describes a new system for measuring the dielectric constant of seawater near 700 MHz. The purpose of this research is to obtain data at P-band for the dielectric constant of seawater that can be combined with previous L-band data for developing a model function valid from 500 MHz to 2000 MHz. A transmission-type cylindrical cavity has been constructed with the TM_{010} mode resonance occurring near 700 MHz. The seawater is introduced via a capillary quartz tube. The dimensions of the cavity have been determined by electromagnetic modelling. The model takes the cavity wall loss into account and can provide accurate estimation of resonance condition for both the empty cavity and cavity with seawater. The errors between the theory and measurement are about 0.07% for the resonant frequency and 0.4% for the quality factor, *Q*. The cavity design, experimental setup and measurement schedule will be presented in the paper.

Index Terms— Seawater, dielectric constant, P-band, salinity retrieval

1. INTRODUCTION

It has been recognized that a P-band sensor (500 MHz-800 MHz) is near optimal for remote sensing of Sea Surface Salinity (SSS); research to extent remote sensing of SSS into this frequency range is starting to be investigated [1] [2]. At these frequencies, the sensitivity of brightness temperature (T_B) to salinity is near its peak. This is illustrated in Fig. 1 which shows the sensitivity of T_B to SSS as a function of frequency and temperature. The sensitivity at 700 MHz is near the peak for warm water. The real advantage of measurements at 700 MHz, however, is in cold waters. An examination of the H- and V- polarization curves for T = 0°C shows that the sensitivity is much higher at 700 MHz than it is at 1.4 GHz at this temperature. The effects of surface roughness, in addition, are expected to decrease at P-band [2].

Due to the concern of radio frequency interference (RFI), spaceborne radiometers for remote sensing of SSS [3][4][5] operate in the band from 1.4 GHz to 1.427 GHz protected by international agreement for passive measurements. Improvements in microwave radiometer technology for identifying RFI are being made [6]; and technology is being demonstrated to utilize transmissions of existing RF systems for remote sensing [7]. Both technologies greatly benefit the potential for remote sensing of sea surface salinity outside of the protected band.

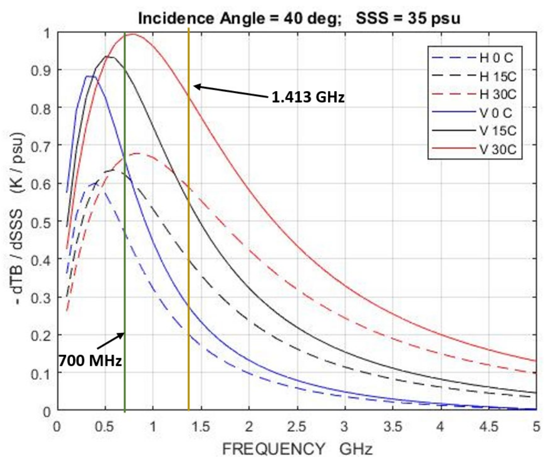

Fig. 1 Sensitivity of T_B to SSS at varius temperature and polarizations

In the past Lang et al. [8] made measurements of seawater dielectric constant at 1.4135 GHz, which led to the development of the GW2020 model function in Debye form [9]. The model function is based entirely on laboratory measurements with an accuracy suitable for the retrieval of SSS. To improve the accuracy of future wide bandwidth retrievals of SSS, new measurements at P-band have been started using a new system designed and constructed for obtaining accurate seawater dielectric data at a frequency close to 700 MHz. The system employs the resonant cavity technique used for L-band. The cavity operates at TM_{010} mode and its dimensions have been determined by electromagnetic modeling. In this paper, the cavity design will be introduced in Section 2. The experimental setup and measurement schedule will be presented in Section 3. Finally, the conclusion will be drawn in Section 4.

2. CAVITY DESIGN

A transmission-type cylindrical cavity has been designed to make seawater dielectric measurements at P-band. Two

probes are placed in the cavity to excite the system; the S_{21} parameter is measured to detect the resonance. Seawater is introduced into the cavity by inserting a quartz tube with a small hole in it along the cylindrical axis of the cavity. The volume of the introduced seawater needs to be very small so that perturbation theory can be used for determining the seawater dielectric constant using the following formulas[10]:

$$\varepsilon' - 1 = 2C\,\Delta f / f, \qquad \varepsilon'' = C\Delta(1/Q), \tag{1}$$

where

$$\Delta f = f_0 - f, \qquad \Delta(1/Q) = 1/Q - 1/Q_0 \tag{2}$$

Here ε' and ε'' are the real and the imaginary parts of the relative complex dielectric constant of seawater, f_0 and f are the resonant frequency before and after seawater is introduced, respectively; Q_0 and Q are the quality factor before and after seawater is introduced, respectively. The quantity C is called the calibration coefficient and must be determined before measurements can be made.

Another reason to keep the volume of seawater in the cavity small is because seawater is very lossy. If the volume of seawater is too large, the Q will be very low after the seawater is introduced, causing errors in computing Δf and $\Delta(1/Q)$ in eq. (2).

An electromagnetic model has been developed to determine the size of the cavity and the tube for obtaining the resonance at the frequency of interest. The resonant frequency of the cavity when operating in the TM_{010} mode is determined from the cylindrical structure of the cavity and does not strongly depend on the cavity height if the loss is low. The equation for the resonant frequency is obtained by matching $\mathbf{E}_z$, the electric field in the z direction, and $\mathbf{H}_\varphi$, the magnetic field in the phi direction, across the inner and outer diameter of the quartz tube. The fifth equation is found by using an impedance boundary condition at the inner side of the cavity wall. From these five equations a z-directed propagation constant, κ_z, is determined. The final equation for the resonant frequency and Q is found from an axial transmission line equation that takes the impedance of the end plates into account [11]. The resonant frequency is usually found using a perturbation approach around zero loss, but this approach is more accurate considering that seawater is very lossy.

The dimensions for the P band cavity are as follows: the diameter of the L band cavity is doubled; the outer diameter of the quartz tube is not changed but kept at a diameter of 3 mm. Several sizes of the inner radius of the quartz tube have been tried but doubling the radius to 0.2 mm has given the best results. The height of the P band cavity is left unchanged. Keeping the outer diameter of the quartz tube the same has the advantage that the external glassware employed at L band can be reused. These parameters have been used in the cavity model. Two cases have been run: first the resonant frequency and Q of an empty cavity have been calculated. The results are shown in Table I and labeled as f_0 and Q_0. The frequency is almost exactly one-half the L band frequency and the Q is similar to the L band cavity Q. A simulation with seawater having 35 psu at 20ºC has been run next. These results are labeled f and Q in Table I. The Q of the cavity with seawater in it has dropped to 3428. The L band cavity had a Q of 4500 under the same conditions. The Q could be increased by reducing the inner diameter of the quartz tube to 0.015mm but this would reduce Δf which is already quite small. The resonant curves for these two cases are shown in Fig. 2.

Following these design specifications, the cavity has been manufactured. The cavity side wall is made of bearing bronze and the top and bottom endplates are made of naval brass. Twenty quartz tubes with outer diameter of 3 mm and inner diameter of 0.2 mm have been obtained. Although only one tube is required, tubes break or become clogged and often must be replaced. Each tube is fused to a quartz socket to enable the quartz tube to interface with the glassware above

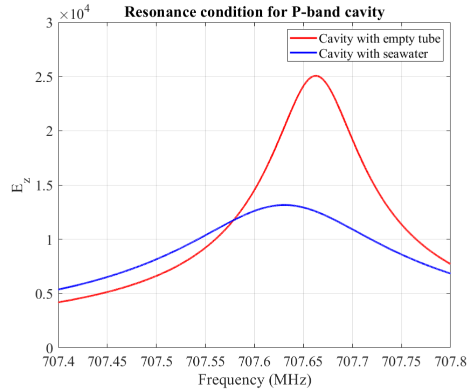

Fig. 2 Modeled resonance curve for cavity with and without seawater

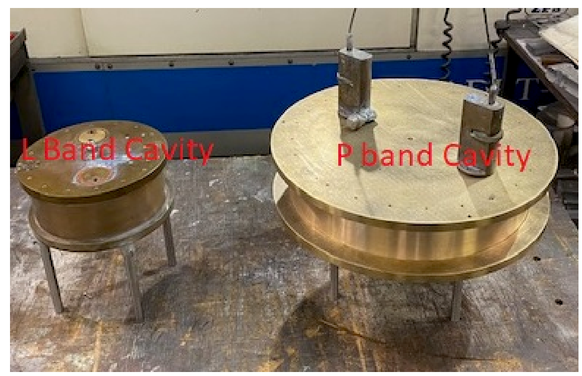

Fig. 3 Manufactured P-band cavity and previous L-band cavity

TABLE I COMPARISON OF MEASURED AND MODELED RESULTS

	Measured	Modeled	Difference
f_0	707.184 MHz	707.663 MHz	0.068%
f	707.151 MHz	707.631 MHz	0.068%
Q_0	7975	7942	0.416%
Q	3415	3428	0.379%

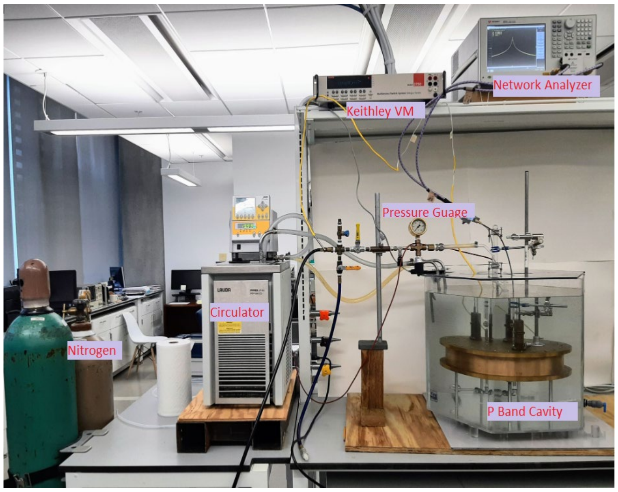

Fig. 4 Experimental setup for P-band measurements

the cavity. A closer look of the cavity and comparison with the previous L-band cavity is shown in Fig. 3.

Measurements have been made for the P-band cavity with and without seawater at room temperature. The seawater used in the measurements is standard seawater with a salinity of 35 psu. Table I shows a comparison between the measurements and modeled results, which are in good agreement with about 0.07% difference in resonant frequency and 0.4% difference in quality factor, Q.

3. EXPERIMENTAL SETUP AND MEASUREMENTS

Preparations are being made to start measurements of seawater. The P-band cavity has been placed in the tank. The tank is filled with coolant whose temperature is controlled by the circulator (Fig 4) and recorded by a Keithley multimeter (Fig 4, top left). The Vector Network Analyzer (VNA) is used to excite the resonance in the cavity and obtain S_{21} parameter for calculating the dielectric constant. The capillary quartz tube has been inserted at the center of the cavity and connected to a series of glass tubes for introducing seawater externally. The glass tubes are connected to a nitrogen tank (Fig 4, far left), which is used to push the seawater or other fluid under test through the quartz tube. The tube used in the system has a slightly larger inner hole size (ID = 0.02cm) compared with the L-band measurement system (ID = 0.01cm), potentially reducing the risk of blockage and increasing the speed of measurements.

Before dielectric constant measurements of seawater can started, the calibration constant, C, shown in eq. (1) must be measured. It will be slightly different for each new tube that is used. Methanol will be used in the calibration process. Gregory and Clarke [12] of the National Physical Laboratories in London have make very accurate measurements of the dielectric constant of methanol as a function of frequency (0.1 – 5.0 GHz) and temperature (10° - 50° C). We will use their values for the dielectric constant of methanol at 700 MHz and 20° C. The procedure is to measure the Δf and $\Delta\left(1/Q\right)$ for methanol using these values obtained in eq. (1) along with the dielectric constant given in their tables to calculate C. Two values of C are obtained: one from the ε' equation and one from the ε'' equation. The two values should be the same and only differ by a small experimental error.

The seawater measurements using IAPSO seawater samples having salinities of 30, 35 and 38 psu at the temperature from 0°C to 35°C are planned to be made. It will be interesting to compare the results of these measurements with the prediction of the model developed from the L band measurements (i.e. by adjusting the frequency P band).

4. CONCLUSIONS AND FUTURE WORK

A system for the measurement at P-band of the dielectric constant of seawater has been established based on the cavity technique. Initial test measurements and the modeled results are in good agreement. In the future, systematic measurements of standard seawater will be made. The results will be combined with previous L-band dataset to construct an accurate model function that covers the frequencies ranging from 500 MHz to 2000 MHz for future wideband salinity retrieval.

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